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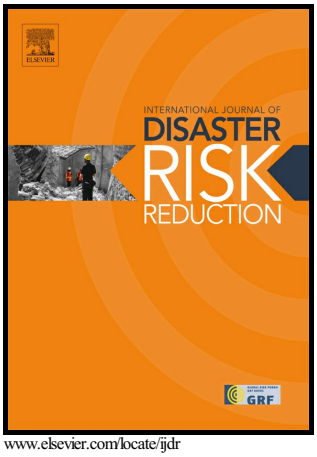

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The complex consequences of volcanic warnings: trust, risk perception and experiences of businesses near Mount Zao following the 2015 unrest period

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Abstract

This paper reports results from a study of business owners carried out in 2016 in the region around Mount Zao, an active stratovolcano in Japan. In April 2015, Mount Zao experienced a period of unrest consistent with magma rising in the volcanic system. This led to alerts and public awareness campaigns, which provoked extensive media interest. This project used a survey and 12 semi-structured interviews to examine the opinions of business people on how the crisis was managed, and how it affected them. It also examined the perceptions of risk and the stories that were told about the potential eruption. Business owners who thought that an eruption would be harmful and that forecasting eruptions is difficult were more likely to be trusting. In general, respondents were very unaware of the risk from the volcano and the hazards that it could produce. The data also show that the impacts of disasters and even warning periods can cascade, much as hazards do: respondents noted that the crisis period effectively extended the time it has taken them to recover from the impact of the Tohoku earthquake in 2011, or brought them low just as they recovered. With increased vulnerability, the warning period at Zao exacerbated their situation, and this was not helped by a lack of scientific information and some perceived "rumours". The paper suggests that public engagement via participatory strategies would be beneficial in reducing risk in this region, because it would enable stakeholders to own their risk and understand it.

Keywords: Volcanic risk; Developed countries; Volcanic unrest; Risk perception; Disaster impacts; Tourist industry

Introduction

Mount Zao is a complex stratovolcano in northern Honshu, Japan (Figure 1). It is historically one of Japan's most frequently active volcanoes (Table 1). It typically erupts basaltic to andesitic composition lavas, and has a long history of minor eruptive activity that is well documented (Ban et al., 2008). However, the last activity was a minor event in 1940, so on the edge of living memory. The volcano is also a popular tourist attraction in Japan, particularly in winter, when its famous "snow monsters" make an appearance, and when the ski slopes are open. It is famous too for its hot springs (Onsen), which are frequented by visitors from the local area and other parts of Japan. The volcano is also at the boundary between two Japanese Prefectures, Miyagi and Yamagata, which

means that there are different locally led approaches to risk reduction on the different sides of the volcano (Cabinet Office, 2015). The volcano is also breached to the east side, such that the risk from hazardous flows is generally higher in Miyagi than in Yamagata (JMA, 2013).

In September 2014, scientists had detected ground deformation around Mount Zao, and in October, the crater lake Okama at the summit turned white. On 7th April 2015, an increase in seismicity was detected, and led to a volcanic alert being issued in the Zao area on 13th April. The seismic activity continued for about a month, and the alert was discontinued by the Japanese Meteorological Agency on 16th June. These events took place in the shadow of the Ontake eruption on 27th September, 2014, which had shocked Japan: the volcano exploded without warning and killed 63 people who were hiking near the summit. The Japan Times reported on 14th April:

> With Ontake's eruption still fresh in people's minds, the latest warning quickly stoked fear in visitors, said a tourism association spokesman for the Zao ski and onsen resort.
>
> "Okama is one of the key tourist spots in Zao," he said, referring to the color-changing lake in Zao's crater, "but people think the resort is already dangerous to enter, just because it has the same name as the volcano."

Many other media sources also made this link between the two volcanoes. Following the alert level, tourism decreased sharply in the region, leading both the Miyagi and Yamagata Prefectures to introduce discount schemes to encourage tourists to return (Kuri et al., 2017). The region is strongly dependent on tourism, both from within Japan and overseas (Kajitani et al., 2013).

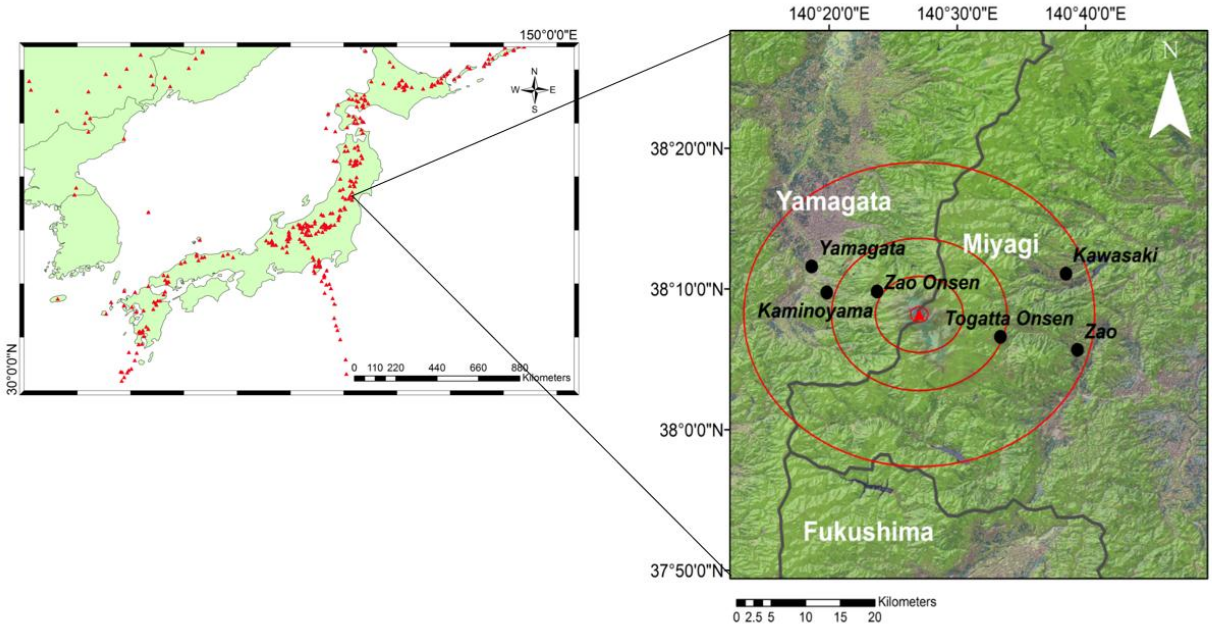

Figure 1. Map showing the area around Mount Zao (red triangle). Red triangles on map of Japan are volcanoes from the LaMEVE database (Crosweller et al., 2012). Red lines are at 1km, 5km, 10km and 20km, to illustrate the distances around the volcano. Zao Onsen is a major ski resort in Yamagata Prefecture; Togatta Onsen is a hot springs resort area in Miyagi. Imagery is Landsat 4-5 MSS, overlaid with an SRTM DEM. Grey lines show the boundaries between Prefectures (white text).

Table 1. Eruption history of Mt Zao. All activity noted here in stage 4 has been located at Okama lake, at the summit of Zaosan. Sources: Ban et al. (2008); Tatsumi et al. (2008); Takebe and Ban (2015); JMA (2013).

Stage	Dates	Eruption style	VEI (where known)
1	c. 1Ma	Pyroclastics	
2	c. 300ka	Lavas	
3	100-300ka	Lavas	
4	30ka to present	Pyroclastics, lavas	
4: historical activity since 1000	C12th-15th	Regular activity – tephra fall	Up to 3
	1620-1625	Regular activity – tephra fall	3
	1669-70	Tephra fall	3
	1694	Moderate eruption	2
	1794-6	Eruptive activity	2
	1804, 1806, 1809	Eruptive activity	2
	1821	Eruptive activity	2
	1830-33	Eruptions, tephra fall	2
	1867	Phreatic activity	2
	1873	Eruptive activity	1
	1894-7	Tephra fall	2
	1906	Small phreatic eruption	1
	1940	Tephra fall	1

A timeline of the disruption caused by the warning is provided in Figure 2. This shows that the crisis was prolonged – the volcano remained restless from autumn 2014 until the time of the fieldwork for this project in 2016. During this time, the alert level was raised to 2 in April and lowered to 1 in June, but warnings continued to be issued into early 2016 due to periods of raised seismicity. More importantly, perhaps, no announcement was made that the crisis was over. During this period, volcanic hazard maps were revised repeatedly and an evacuation plan was announced almost a year after the initial alert (Figure 2).

In this paper, we investigate the impact of this alert on local businesses, focussing in particular on the impacts, role of the media and the respondents' perceptions of risk and uncertainty surrounding volcanic activity.

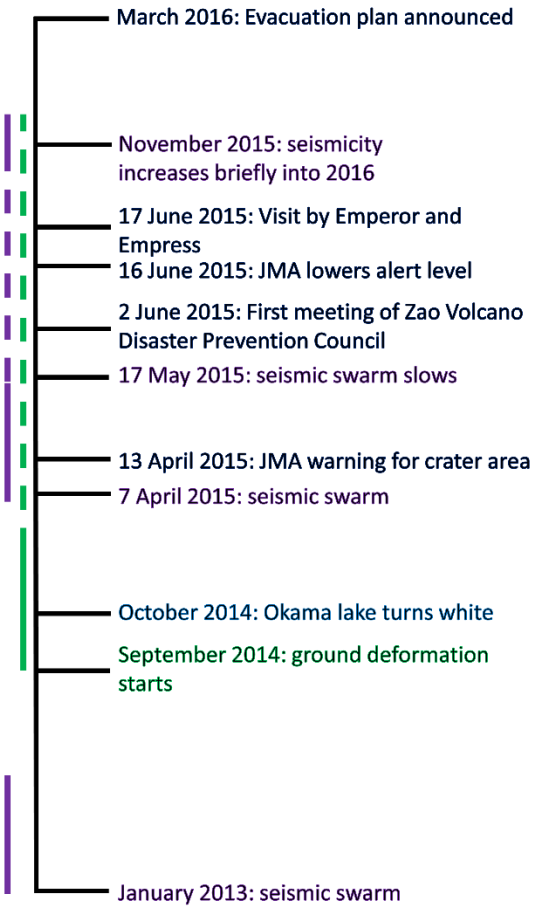

Figure 2. Timeline of the volcanic crisis at Mount Zao. Seismic events are shown in purple and ground deformation in green. Social and warning information is dark blue.

Background

Volcanic risk and warnings

Volcanoes produce a wide range of hazards that have diverse impacts on lives and livelihoods. The hazards produced vary between eruptions and between volcanoes, and can be catastrophic in magnitude. Previous studies (Donovan et al., 2014; Donovan et al., 2015; Eiser et al., 2015; Greene et al., 1981) have looked therefore at public perceptions of the likelihood of different hazards. This provides some information on public awareness of the types of hazard, as well as their likelihoods in a particular context. Impacts from eruptions may also be varied in magnitude and duration. However, it can be challenging for populations to understand potential impacts prior to an eruption (Dominey-Howes and Minos-Minopoulos, 2004; Gregg et al., 2004). Impact perceptions are therefore also an important variable in understanding risk perception for volcanic hazard.

The impact of volcano warning periods on populations has been documented in a number of case studies, particularly that of La Soufrière de Guadeloupe in 1976 (Hincks et al., 2014), in which phreatic activity led to a costly evacuation. However, similar issues have occurred in periods of heightened alert level elsewhere (Donovan et al., 2012; Donovan and Oppenheimer, 2015). This has led to considerable anxieties among volcanologists about “false alarms”, and discussion of how to engage with affected populations. Nevertheless, there has been relatively little work on the social dynamics of an alert period that does not include any observed surface activity.

Eiser et al. (2012) discuss the issue of warning, and frame it in the context of signal detection theory, suggesting that the interpretation of a risk signal will ultimately depend on what kind of errors people are willing to accept. They also caution against the importation of results from other fields in understanding disaster risk, because the kinds of uncertainty that are experienced may be different. However, there are some examples from other fields that have dealt with "near-misses" in a systems framework (Dillon, 2008; Dillon and Tinsley, 2008; Tinsley et al., 2012). These studies also suggest that participants with information about near-misses might have lower perceived risk – and that therefore "false alarms" can damage risk perception. However, in the context of catastrophic risk, the argument of Eiser et al. (2012) and indeed Hincks et al. (2014) would be that the Precautionary Principle applies – and there is evidence that in the context of risk, people would generally prefer to be warned (Eiser et al., 2015).

An additional issue during warning periods is that of trust (Bronfman et al., 2016; Eiser et al., 2008; Haynes, 2007; Kasperson et al., 1991; Paton, 2008; White and Eiser, 2005). Trust can have a significant impact on people's willingness to respond to warnings, and also their response to information more generally (Wachinger et al., 2013). Trust in different sources of information varies between places – for example, Haynes et al. (2007a) found that Montserratians trusted family and friends. This was also true of Icelanders – but not of the UK public – in relation to volcanic hazard from Iceland (Eiser et al., 2015). Warnings issued by untrusted groups are unlikely to be successful in generating a behavioural response (Mileti and Sorensen, 1990).

Risk, businesses and cascades

The links between risk perception and financial interests have been investigated by social psychologists interested particularly in the motivations behind trust (e.g. Eiser et al. (2008)). People are more likely to trust groups that they do not perceive as having financial interest (ie potential financial gain or loss) in the outcome of a risk decision – so if a group is perceived as potentially gaining from a decision to take a precautionary approach to risk, then that group might be less well trusted by the public, and the public may be more sceptical about the risk. This parallels circumstances in which political figures or the media are less well trusted because their motivations are perceived to be political or sensational rather than altruistic (Haynes et al., 2007a): ultimately, perceived motive can be important in trust (Critchley, 2008). However, in the context of volcanic risk, populations can also stand to experience considerable losses in a crisis, and their trust in different groups may subsequently be affected by their experience of loss. Volcanoes are frequently tourist attractions (Bird et al., 2010; Erfurt-Cooper and Cooper, 2010). This means that they are visited by large numbers of people who have very little local knowledge of the topography or the risk. Furthermore, volcanic eruptions can occur at short notice, as did the Ontake eruption, and tourists hiking near the summit may not be warned in time.

The area that we have selected for this study is prone to multiple hazards, including earthquakes and extreme weather events. In 2011, the Great East Japan Earthquake and Tsunami (GEJET) had a catastrophic impact across the Tohoku region. Furthermore, it caused a crisis at the Fukushima power plant that generated considerable fear across Japan (Tateno and Yokoyama, 2013). The economic impact of the crisis was significant (Bachev and Ito, 2014; Yamane et al., 2013). Bachev and Ito (2014) also found in their study that "harmful rumours" were perceived as a significant factor in reducing product uptake. Businesses worry about the stigma associated with risk perception that is excessive (Schulze and Wansink, 2012), and so their perceived source of this is also important.

The context in which we have situated the study thus provides an interesting one in which to assess the impact of a volcanic alert period that did not result in an eruption: the area was already

experiencing economic challenges, and had also suffered considerable damage in the earthquake. Recent work has studied the complexity of cascading hazards, and also some of the challenges that are endemic in an interconnected world – both through supply chains and communication (Pescaroli and Alexander, 2015; Tierney, 2007). The potential for the impact of GEJET to exacerbate vulnerability to the warning period and possible eruption is therefore also of interest in this paper.

Risk perception and experience

Social psychologists have noted the importance of "seeing" in risk perception. The availability bias, for example, emphasises the importance of past experience in regarding a risk as significant (Tversky and Kahneman, 1973). More recent work backs up this observation (Demuth et al., 2016; Ho et al., 2008) and also argues that perception of a risk is not adequate for action: other factors are also significant (e.g. Wachinger et al. (2013)). Work on climate change has also demonstrated that "belief" in climate change – awareness of the risk – is also partially dependent on having viewed the effects (Reser et al., 2014; Spence et al., 2012), as well as on socio-economic factors, for example. The question of when people act on a risk they perceive is more complex (Sims and Baumann, 1983), since priorities come into play: those who cannot afford to leave their businesses are much less likely to do so than those who can, for example (Fischhoff and Morgan, 2009; Gaillard, 2008). Thus, understanding the feelings of business owners towards alerts is important. In addition, it is important to understand the most effective ways of engaging with communities during warning periods, and the best methods to ensure that scientific and risk information is communicated clearly.

Work in the social studies of disaster risk strongly emphasises the need to engage with communities so that they can cope with the risks that they face (Eiser et al., 2012; Gaillard and Mercer, 2013; Wisner et al., 2012), and this has been recognised widely in scientific communities involved in outreach work, such as volcano observatories. This means that risk communication is not a straightforward, mono-directional process: it is not a matter of informing people about the risk or the science alone. While some basic scientific knowledge is important, this should be conveyed through dialogue with policymakers and the public (Donovan and Oppenheimer, 2014; Irwin, 2014; Irwin and Wynne, 1996; Jasanoff, 2004). Science does not take place in a vacuum, and populations have to be able to assess where evidence comes from and what it means. In order to facilitate this process, the needs of communities and their expectations of experts have to be established.

In this paper, we investigate the 2015 crisis at Mount Zao in Japan, focussing on the responses of business owners and the impact of the crisis on their lives. We examine in particular their perception of hazards and risk, and their levels of trust in particular agencies. We also discuss their concerns about false alarms and future events, and their views about their needs. We also assess differences between Miyagi and Yamagata Prefectures, which differ both in their disaster mitigation strategies and information, and in their physical geography – Miyagi is on the east side of the volcano, which is more hazard-prone than Yamagata (according to the hazard maps produced by the Japanese Meteorological Association).

Methods

This project involved 12 semi-structured interviews in January 2016, followed by a survey of 80 businesses in the Zao region. The interviews were designed to investigate the impacts of the 2015 volcanic crisis on Mount Zao on local businesses, particularly those that depend on tourism. Interviewees were asked about the business impacts of the crisis; their perception of the volcano and volcanic risk before and during the crisis; their access to information about the volcanic crisis; the role of government, media and tourist boards in managing the crisis; their own role in managing the risk; and what they would like to see done to support them in a future crisis. The responses to

the interviews were coded thematically using a grounded theory approach. They were also used in the subsequent design of the survey. Interviews ranged in length from 30 minutes to 2 hours, and took place in Togatta Onsen, Zao Onsen and at businesses along the roads on the lower slopes of the volcano.

Following the interviews, themes that had emerged were identified and included in the survey to examine whether or not the survey respondents had similar experiences – for example, interviewees mentioned that the Emperor's visit had helped, so this was included in the survey. Another issue that came up regularly was the current state of the volcano, so the survey was also used to explore that further and check whether or not the views of interviewees were shared in the wider group.

The survey was designed to examine similar issues to the interviews, and also to explore the dimensions of trust and uncertainty of information in volcanic crisis management on Zao. The questions analysed in the survey are shown in Table 2. In addition to these, a number of questions about the financial details of business impacts were asked and will be written up elsewhere. Respondents were also asked to provide some demographic details: age, gender, nationality, town and state, how long they have lived in the area, what kind of business they own, and whether or not they have business impacts that they can attribute to the 2015 alerts. There were also two comments boxes – which sources gave them information in 2015, and how their business was affected by the alerts. Basic frequencies for the data using a slightly different methodological approach are given in Kuri et al., 2017. The response rate for the survey was 33.1% (80 questionnaires were returned out of 242 sent out by post).

Statistical methods

The surveys used a scale variable for measuring perceptions. The use of scale variables in statistical analysis is contested (Jamieson, 2004), and so care was taken here to assess how the scale was used (Norman, 2010). We compared the results from parametric and non-parametric tests, and these suggested that the intervals between units on the scales (which had 5 points) were used consistently. We have treated the variables as continuous for the purpose of regression analyses. Given that the distributions failed normality tests, we have carried out non-parametric analyses on the data (Kruskal Wallis, Mann-Whitney, Chi-square). We report both means and medians in the tables. Care was taken to avoid significant test results that occur because of small groups, due to the relatively small size of the dataset. Such results were discarded.

Table 2: questions in the survey.

Variable	Question	Scale
Interest	What are your reasons for being interested in Mount Zao?	Selection with other field
Hazards	If Mount Zao erupts, how likely is it to produce the following hazards? (Lava flows, pyroclastic flows, gas emissions, ashfall, mudflows, landslide, phreatic explosion, mud eruption)	Extremely likely (1) to extremely unlikely (5)
Frequency	How often do you think the volcano erupts?	Selection (1 in X years), with X=10, 50, 100, 250, 500, 1000 and do not know
Impacts	If Mount Zao erupted, how severe do you think the impacts would be in terms of: damage to property and infrastructure; damage to livelihood; loss of life	Scale of extremely high (1) to extremely low (5)
Evacperiod	If Mount Zao erupted, do you think it would be necessary to evacuate…	Selection between short-term (less than 3 months); long-

		term (more than 3 months); a limited area; do not think evacuation necessary
Forecast	How easy do you think it is for scientists to forecast volcanic activity on a scale of: minutes, hours, weeks, months, years	Scale from definitely possible (1) to impossible (5)
Trust	How much do you trust the following groups to provide information about volcanic activity at Mount Zao? (Scientists, JMA, Emergency services, local government, national government, tourist industry, mass media, social media, friends and family)	Scale from trust completely (1) to do not trust at all (5)
Responsibility	To what extent are the following groups responsible for informing you about volcanic activity? (groups above)	Scale from completely responsible (1) to not at all responsible (5)
Statements	To what extent do you agree with the following statements? (If too many warnings are given, people stop taking them seriously; it's always better to be safe than sorry; if one thinks there's any risk at all, people must be warned; warnings that turn out to be unnecessary do more harm than good; if there is any chance that businesses will be harmed by an alert, it is better not to warn the population until we are certain an eruption will happen)	Scale from completely agree (1) to completely disagree (5)
Effects2015	Can you tell us how the alerts affected you and what you think about the current state of the volcano? This section also included a question about whether or not a visit by the Emperor helped improve sales.	Selection from options (Yes = 1, No = 2)
Business impacts	Respondents were asked whether or not the alert affected their business, and to estimate their loss of sales. They were also asked if there were measures that would have helped them.	Yes/no, and numerical/text answers.
Busimpqual	To what extent was your business affected?	Comments field
Infosources	What sources of information did you use during the crisis?	Comments field
Maxred	What was your maximum reduction in sales?	Text box
Avred	What was your average reduction in sales?	Text box

In addition to the variables in Table 2, a number of other variables were calculated. This was based on tests for reliability of scale (Cronbach's alpha). These additional variables are shown in Table 3.

Table 3. Cronbach's alpha for calculated variables. A value >0.7 is generally considered robust (Field, 2000; Nunally and Bernstein, 1978).

Name	Formulation	Cronbach's alpha
Allhaz	Average of all hazard variables	0.93
Allimpact	Average of all impact variables	0.73
Allforecast	Average of all forecast variables	0.75
Alltrust	Average of all trust variables	0.92
Allresp	Average of all responsibility variables	0.89
Shortterm	Average of short-term forecast variables	0.85
Medterm	Average of longer-term forecast variables	0.88

Trust_exp	Av of trust scientists, JMA, emergency services	0.84
Trust_govt	Average of trust in local and national governments	0.86
Trust_inf	Av of tourist industry, social media, mass media, friends and family	0.86
Resp_exp	Av of responsibility of scientists, JMA, emergency services	0.79
Resp_govt	Average of responsibility of local and national governments	0.90
Resp_inf	Av of tourist industry, social media, mass media, friends and family	0.81
Precaution	Average of 2 precaution statements	0.64
False alarms	Average of 3 false alarm statements	0.75

Results

This section initially presents the demography of the respondents, and then the survey data. It presents the survey data first to elucidate general patterns, and then uses both the qualitative survey data and the interview data to draw out some of the nuances in the results.

Demographics of respondents

Survey

The mean age of respondents was 58, and the majority were male (71%), representative of the higher incidence of male leadership of businesses in the area. All respondents were Japanese, and 55% were from Yamagata Prefecture, with 44% from Miyagi (one was from Tokyo). Over 70% had lived in the region around the volcano for more than 20 years (this correlated with age, unsurprisingly, and care was taken to avoid multicollinearity in the subsequent analysis). Most were involved in tourism (either education or accommodation) – 65%, with the rest involved in retail and food; and 90% had experienced some form of loss during the 2015 warning period. Women tended to be younger (U-132.5, $p<0.001$) and to have (therefore) lived close to the volcano for less time (U=210.5, p=0.008).

The survey respondents were hotel owners (56%), retailers (14%), educational tourist agencies (9%) and food vendors (20%), with one respondent not identifying in any category. The room rates of hotels varied by an order of magnitude, suggesting that a range of types and levels were covered. The number of rooms in the hotels varied from 5 to 200.

Interviews

Interviewees were based in hotels (6), a farm, an association and four retail stores (three of which were food-related;). The hotels ranged from over 100 rooms to around 10 rooms. Nine interviews took place in Miyagi, and three in Yamagata.

Hazard perception

Survey

The data suggest that most respondents regarded lava flows, landslides and pyroclastic flows as unlikely (Table 4). Ash, mudflows, explosions and gas emissions were regarded as slightly more likely. This is interesting and reflects the qualitative results that suggest that risk perception was informed in part by recent volcanic activity elsewhere in Japan, rather than by the history of Mount Zao itself.

There were significant differences in hazard perception by Prefecture, with respondents from Yamagata Prefecture consistently viewing hazards as less likely than those from Miyagi Prefecture (Table 4).

Table 4. Results for the hazard variables. Note that 5 is extremely unlikely, while 1 is extremely likely. Mann-Whitney tests that were significant for Prefecture are reported with their p-values (the one resident from Tokyo was excluded).

VARIABLE	MEAN	MEDIAN	STANDARD DEVIATION	NUMBER OF RESPONSES	MANN-WHITNEY (P)
LAVA FLOW	4.4	5	0.98	77	442 (<0.01)
PYROCLASTIC FLOW	4.1	4	1.1	77	411 (<0.01)
ASH	3.0	3	1.4	81	248 (<0.001)
EXPLOSIONS	3.3	3	1.3	77	388 (<0.01)
GAS EMISSIONS	3.2	3	1.4	78	469 (<0.05)
MUDFLOWS	3.4	3	1.3	77	396 (<0.01)
LANDSLIDE	3.8	4	1.1	77	n.s.

Respondents perceived the frequency of eruption as relatively low – with the modal value being "1 in 100 years" (61%). Only 1% thought that there was one eruption every 10 years, and 10% thought one every 50. A further 20% thought that there was one eruption every 500 years, with 1% thinking every 250 years and another 7% every 1000 years. There were no significant predictor variables.

Interviews and comments

In general, interviewees from Yamagata prefecture viewed hazards as less likely than people from Miyagi prefecture. This is partly because the mudflow paths were perceived as mainly affecting the east of the volcano, since the volcano opens to the Miyagi direction (and therefore the risk to Miyagi is actually greater). Mudflows in general seemed to be more "real" to interviewees than other hazards. People viewed the risk as minor, and focussed on the role of the media in amplifying the risk. Several suggested that there should be national thresholds for the issuance of warnings.

Perceived impacts of a potential eruption

The next set of variables in the survey examined the perceived impacts of an eruption, focussing on the likely impact of an eruption on livelihoods, property and loss of life, and also examining views about the likely evacuation period.

Table 5. Frequency data for the impact variables

VARIABLE	MEDIAN	MEAN	STANDARD DEVIATION	NUMBER OF RESPONSES
DAMAGE TO PROPERTY	4	3.43	1.81	79
LIVELIHOOD IMPACT	1	1.85	1.52	80
LOSS OF LIFE	4	3.82	1.40	79

In general, most respondents thought that loss of property and life was unlikely, but loss of livelihood very likely (Table 5). They also thought that the impact in terms of evacuation would be

minimal – 45% thought no evacuation at all; 32% thought an evacuation of a very small area might be necessary – e.g. around the summit; 11% thought a short evacuation of less than 3 months might be needed; and 10% thought that a longer-term evacuation might be necessary.

The perceptions of loss of property and loss of life correlated strongly with the hazards variables – those who viewed the hazard as high also regarded the chance of losses as high. However, the livelihoods variable did not correlate with these variables, except for ash (and only at the 5% level – all other correlations were at the 0.1% level). This suggests that respondents' experiences during the 2015 warning period might have coloured their responses regarding the impact on livelihoods – since many had experienced this without any eruptive activity at all, though there is also likely a slight attenuation effect due to the skew on this variable (Table 5; note that Pearson's correlation coefficient shows the same effect). Correlations are shown in Table 6.

Table 6. Significant correlations between the hazard variables and the impact variables.

	PROPERTY (P VALUE)	**LIVELIHOODS (P VALUE)**	**LOSS OF LIFE (P VALUE)**
LAVA FLOWS	0.47 (<0.001)	n.s.	0.45 (<0.001)
PYROCLASTIC FLOWS	0.43 (<0.001)	n.s.	0.38 (0.001)
ASH	0.51 (<0.001)	0.24 (<0.05)	0.54 (<0.001)
PHREATIC ERUPTION	0.36 (0.001)	n.s.	0.36 (0.001)
GAS	0.41 (<0.001)	n.s.	0.34 (<0.01)
MUDFLOW	0.53 (<0.001)	n.s.	0.45 (<0.001)
LANDSLIDE	0.54 (<0.001)	n.s.	0.44 (<0.001)

Perceptions of evacuation period similarly were associated with perceptions of hazard. This was a categorical variable, so the Kruskal Wallis test was used and showed that with the exception of lava flows and phreatic explosions, all the hazard variables had significant results, with lower perceptions of hazard associated in general with the view that no evacuation would be necessary.

In summary, the impact variables were mostly related to perceived hazard. The exception is the perceived loss of livelihoods, which was independent of hazards, possibly because losses were experienced even without a volcanic eruption in 2015.

The ease of forecasting eruptions: dealing with uncertainty

The survey respondents were asked about five different timescales of forecasting – minutes, hours, weeks, months and years. In general, respondents viewed forecasting as relatively difficult, particularly over the longer timescales (median = 4; shorter timescales median =3). However, this was clearer over the long timescales – at short timescales, there were more respondents who viewed forecasting as possible (scoring 1 or 2). For scales of hours and weeks, the distribution is close to a normal distribution, whereas on the minutes scale the modal value is 5, but with 1 and 2 both scoring more hits than 3 and 4.

Those who viewed the risk to property as high also thought that forecasting over longer timescales was possible ($\rho = 0.30$, $p<0.01$). There were a number of strong relationships between these variables and the trust variables (below).

Precaution and false alarms

There were five statements about the communication of risk under conditions of uncertainty, particularly given the possibility of false alarms. These were grouped into 2 new variables, precaution and false alarms.

Older people tended to disagree that unnecessary warnings do more harm than good, and also to disagree that warnings should not be issued if there is a risk of harm to businesses. People from Miyagi were also more likely to disagree that unnecessary warnings are problematic ($U=913$, $p<0.05$). The view that too many warnings could be problematic was associated with people who were not very trusting ($\rho=-0.39$, $p<0.001$) and who did not hold others as responsible ($\rho=-0.29$, $p<0.01$). They also tended to think that impacts would not be significant ($\rho=-0.36$, $p<0.001$). People who thought that businesses should only be warned if eruption is certain also tended not to trust experts ($\rho=-0.39$, $p<0.001$).

There were significant cross-correlations between precaution and false alarms ($\rho=-0.63$, $p<0.001$), so partial correlations were used instead of Spearman's ρ, controlling for false alarms when correlating other variables with precaution and vice versa. Precaution was strongly associated with the view that impacts would be severe ($R=0.41$, $p<0.001$) and was associated with the view that short-term forecasting is straightforward ($R=0.33$, $p<0.01$). Those who advocated precaution tended to be trusting ($R = 0.40$, $p<0.001$), particularly of experts ($R=0.38$, $p<0.001$), with government and then informal sources trailing.

People who thought that the media were unhelpful tended to be sceptical about precaution ($U=464$, $p=0.001$) and concerned about false alarms ($U=1{,}137$, $p<0.001$). People who view the volcano as safe also tended to reject precaution ($U=512$, $p<0.05$), and also to agree that too many warnings can be problematic ($U=942$, $p<0.05$). The opposite was true for those who viewed the volcano as still uncertain.

Trust and responsibility

Two sets of variables concerned the agencies that are best trusted by the respondents, and those regarded as responsible for providing them with information.

In general, trust in scientists, the JMA and emergency services (median = 3) was relatively high compared to trust in the governments, media, tourist industry and friends and family (median = 4). Responsibility was regarded as high for scientists, the JMA and emergency services (median = 2) and slightly less for the other groups (median =3).

Trust (alltrust) was associated with a range of other variables (see supplementary data for correlation matrix). Those who viewed hazard as high also tended to be trusting ($\rho = 0.39$, $p<0.001$), as did those who generally felt the groups had responsibility for warning them ($\rho=0.39$, $p<0.001$). Those who regarded forecasting as challenging tended not to be trusting ($\rho=0.44$, $p<0.001$; $\rho = 0.26$, $p<0.05$). Those who thought the impacts would be severe also tended to be trusting ($\rho=0.57$, $p<0.001$). These patterns were across the variables (alltrust), but some were more marked with different groups. Trust in governments and informal sources was more strongly associated with these groups being responsible for warnings. Those who felt that the media were unhelpful were also less likely to trust the JMA, the national government and both mass and social media.

Responsibility (allresp) was also associated with other variables as above, possibly due to collinearity with trust (Spearman's correlation with alltrust = 0.39, $p<0.001$), but was not associated with longer term forecasting or hazards, or with the view that the media were unhelpful. While the responsibility of government was strongly associated with trust in local government, scientists,

emergency services, tourist industry and friends and family (significant at 1% level), the links for the JMA, national government and media sources were significant at the 5% level. The view that scientists had responsibility for warning was associated with higher hazard awareness (ρ=0.25, $p<0.05$). Women tended to regard informal sources as holding responsibility for warnings (U=163, $p<0.001$).

In summary, trust was associated with holding agencies responsible for warnings, with viewing risk as significant and thinking that forecasting would be relatively straightforward.

Predicting trust

Based on the correlations, a hierarchical regression model was used to predict trust, entering first "allimpact" and then short-term forecasting, and then precaution and false alarms. The results were significant for a model incorporating impacts and forecasting: respondents were more likely to be generally trusting if they also tended to believe that the impacts of an eruption would be significant, and could be forecast. This might suggest that trust was slightly associated with knowledge of outcomes. The best model also included false alarms, but not precaution, which did not significantly improve the result (Table 8; R^2 = 0.51). There was no significant multicollinearity detected.

Table 8. Regression results for trust

Variable	β	t	p-value
Impacts	0.48	5.53	<0.001
Short-term forecasting	0.37	4.46	<0.001
False alarms	-0.17	-2.00	<0.05

The 2015 alert

Impacts, information and the media

The respondents were asked for their views on whether the number of tourists reduced, whether the emperor's visit had helped to bring back tourists, and whether or not the media were unhelpful during the 2015 crisis. They were also asked about the current status of the volcano – whether it is now safe, still uncertain or still uncertain but eruption is less likely than in 2015 (referred to as "Effects 2015" in Table 2).

In total, 78% of respondents felt that the alerts had reduced the number of tourists, but only 10% felt that the emperor's visit had helped to bring people back (in contrast with interviewees, who emphasised this as a useful measure). Interestingly too, only 44% viewed the role of the media as unhelpful (though there were a number of qualitative responses later in the survey that condemned the media strongly). The mean maximum reduction in sales was 37% and the mean average reduction was 27%. Those with a high maximum reduction estimate also tended to be against precaution (ρ=0.43, $p<0.001$) and slightly less likely to trust experts (ρ=0.30, $p<0.05$).

In terms of the current status of the volcano, 35% regard the volcano as now safe, with 36% regarding it as still uncertain, and 45% saying uncertain but less likely to erupt (some had agreed with both uncertain and uncertain but less likely).

Those who regarded the media as unhelpful were less likely to think the volcano would cause loss of life (U=456, $p<0.01$). They were also more likely to be younger (U=898, $p<0.05$) and to regard hazards as generally unlikely (U=156, $p<0.05$).

People who thought that the volcano is now safe were more likely to think that loss of life is very unlikely ($U=419$, $p<0.01$). They were also more likely to think that the hazards were generally low ($U=389$, $p<0.001$). Those who thought it still uncertain showed the opposite pattern.

In general, these results suggest that the respondents who regarded the volcano as lower risk in terms of hazards and impacts were more likely to think that the media were unhelpful and that the volcano is now safe.

The impacts were backed up in the qualitative results. Many of the text comments on the survey suggested a "huge blow", or "significantly lower sales", partly because "tourists decreased". One stated, "Customers ceased to exist throughout Zao Onsen". Others mentioned that although there was some help for hotels (via coupons), this was not much use for restaurants. This backed up the views of interviewees – there was a significant decline in sales. However, there were variations between respondents on how long it took to pick up again – with some saying it was a few months, and others stating that it was continuing at the time of the study.

Qualitative responses in the survey for the main sources of information used by the respondents were coded as 0 or 1 for media, experts, government, institutions, friends. These were used in Mann-Whitney tests to look for significant results. Those who obtained information from the media tended to be more trusting of experts ($U = 383$, $p<0.01$). They also tended to think that short-term forecasting is relatively straightforward ($U = 399$, $p<0.01$), and agreed that "it is better to be safe than sorry" ($U=482$, $p<0.05$). Those who used government sources tended to think that short-term forecasting is harder ($U=798$, $p<0.05$).

Many respondents commented in the text boxes and in interviews on the negative impact of the alert as publicised by the media. However, survey respondents overwhelmingly also stated that they got information during the crisis from the media (72%), particularly via the television. Relatively few obtained information from government (25%) and fewer still from experts (9%) or institutions (11%). Interviewees argued that there should also be reporting when the volcano is safe again – so some form of positive non-news that would encourage visitors to go back again – and this was suggested by survey respondents as a measure they would like to see. There was a lot of concern that people did not know that the area is now safer and that they had essentially forgotten about it. Survey respondents and interviewees repeatedly used the phrase "rumour damage" to describe the impacts on their business, to the point where there was little separation between the warning and the rumour. This is consistent with the relationship between concern about false alarms and trust in different groups: the alert was closely associated with the view that warnings can be harmful. The failure of the media to then report that the volcano was safe was a source of considerable irritation to the interviewees, who also felt that they wanted more information from scientists.

Some important observations and questions that came from interviewees concerned the issue of civic responsibility – in contrast, perhaps, to the behaviour of the media. One hotel, for example, had taken on additional supplies and safety equipment to provide to guests. Some mentioned that they had also been very proactive in obtaining information so that they could make sure that their guests were prepared. They were concerned, though, about the procedures in evacuation: very few respondents really knew how this would work. One mentioned the shelter in Togatta, but others were unaware of its existence. Most interviewees had some awareness of seminars being organised in their areas, including some expert seminars, and some organised by disaster management agencies. They had felt that these were useful but there could have been others. Some respondents had not been able to attend the seminars. Seminars in general were more valued in Miyagi than Yamagata.

Governance

An overwhelming issue in the eruption crisis, as perceived by business owners interviewed, was the consistency of issuance of alerts across Japan. This was linked to the view that, for example, some volcanoes have lots of earthquakes without alerts and so the alert at Zao was premature. It was also linked to the challenges with media coverage and with getting information and evidence from the authorities. There are several issues here. One is the lack of understanding of risk and particularly uncertainty in a volcanic crisis, and also the diversity between volcanoes in general. Some of this could be aided by education programmes, but a more productive approach would be to use participatory methods to involve the communities in risk reduction and use their local knowledge. There was also a clear distrust of some kinds and sources of information: experts were better trusted than other sources, but there was not a consensus on who should provide warnings. There was no awareness of any alert level system, for example, and yet there is such a system in Japan.

In terms of government management, there were slight differences between Prefectures. Both Prefectures did use coupon schemes to try to help businesses recover. However, respondents felt that this should have been accompanied by statements about the safety of the region once the alert was over: the aid should be both financial and informational. Furthermore, there were issues around the use of the coupons: a coupon giving a percentage off the cost of accommodation is not much use to shops, and tended to lead to visitors going to the more expensive hotels, so the cheaper and smaller hotels tended to miss out. Since many of the expensive hotels were part of chains anyway, and could recoup losses from other branches around Japan, this was viewed as particularly unfair. To some extent, the visit of the emperor in June 2015 was useful in communicating that the area was safe again, although it was less highly regarded in the survey than it was by interviewees.

Several interviewees were philosophical about the risk of an eruption, commenting that there was nothing they could do about it, and they would deal with it if it happens but not before. While some did view the crisis as a “false alarm”, others thought that the fact that there had been a crisis but nothing had affected them meant that future crises would also not affect them. This suggests that there may be risks in failing to communicate at least some of the explanation for the alert.

Experiencing place

Cascading crises

Some interviewees struggled to distinguish the impacts from the volcanic alerts from the long-term impacts of the Great East Japan Earthquake and Tsunami (GEJET), which occurred in 2011. GEJET had a huge impact on the region, not least because of the implication that the entire Tohoku region was rendered dangerous from the radiation at Fukushima. There was considerable frustration at the media coverage of GEJET, which was viewed as promoting this confusion. The volcanic alert then hit the economy during the recovery period. This suggests that impacts of disasters can also cascade, even if the disasters themselves are not physically linked – one survey respondent suggested that there was a “synergistic” relationship between these two events. For example, one interviewee had had to spend a lot of money to fix her house after GEJET since she did not have insurance. They had also suffered damage to their warehouse, and had to restore all of this at the same time that the alert was taking place. Another interviewee estimated that the combination of the two events had led to the closure of 30 hotels of the 200 in the region. Others felt that they had just about recovered from GEJET at the time of the alert, and then they were hit again.

Analogue events

The Ontake explosion was also mentioned by all interviewees and some survey respondents as having made things worse, because there was an assumption (also made by the interviewees) that

the same thing could happen at Zao. This had two effects: that people were less likely to come because hiking at the summit is a key attraction; and that many of the interviewees thought that volcanic hazards were restricted to the area close to the summit. Indeed, it was clear that analogue events were important in conditioning people's responses to the crisis. The other volcano that was familiar to interviewees was Sakurajima – and again this played a major role in conditioning their interpretation of the hazard – that the plume can be observed by the eye, and therefore since no plume could be seen at Zao, there was no risk. Whether or not they were concerned about the risk was therefore affected by the analogues with which they were most familiar. Their familiarity was based both on news reports and on the presence of family and friends in other regions – for example, one interviewee mentioned that he had a friend in Nagasaki who kept him informed about the status of Sakurajima.

Cultural memory

Several interviewees commented that they had never really thought about Zao as a volcano – they thought only about the Onsen. The 2015 crisis was the first time they recollected thinking about volcanic risk. Even after the crisis, one respondent stated that Zao is not a "magma volcano". This was linked to their business interests: many tourists come to Zao, but they come primarily for the Onsen, Okama lake and the snow monsters. These are the objects dominantly associated with the area, rather than the fact that it is volcanic (even though both the Onsen and Okama are the result of the volcanic activity). The volcanic activity is largely unseen. This was also linked with the idea of rumour: because the earthquakes under the volcano were not felt earthquakes, and from the surface nothing had changed, it was difficult for people to perceive any difference when the alert was called. They were completely reliant on the warnings from experts and government.

Respondents from Miyagi Prefecture tended to have heard about the past history from their parents, but viewed it as very long ago, and only affecting the top part of the volcano. A respondent from Yamagata mentioned that they were aware of an old volcanic crater, and that there was a landslide on Zao 80 years ago, where the ski slopes are now located. One respondent did mention the Zao monopoly game, which includes a story about the volcano: a myth that the Lord of the region – the famous Samurai Masamune Date – sent his seventh son, Munetaka Date to dance on the volcano to prevent an eruption in the seventeenth century, at the suggestion of a fortuneteller. Respondents also tended to identify strongly with their Prefecture – commenting that Yamagata faces different risks and has different coping strategies to Miyagi.

Perception of space

Several interviewees commented that tourists from further away tended to, in their view, overestimate the risk because they were not familiar with it. However, this view was not universal – one interviewee felt that local visitors were more frightened because the news had not spread too far away. This interviewee also noted that many of the tourists do not have very good geographical knowledge of the area and would telephone to ask about events that were very distant from Togatta. Several interviewees also mentioned the problem that tourists lack knowledge of the volcano's topography, which is very complicated. Survey respondents further noted that this lack of knowledge extends to the TV stations and therefore complicated the media problems. In general, the lack of knowledge about the geography of the region was a source of frustration closely linked to media coverage. However, the respondents themselves also had questions about the geography of the region, particularly the names of different volcanoes in the area – some did not know which mountain was referred to as Zao (since there are several peaks in the Zao system, formed by past lava domes).

The issue of distance perception was also important – several interviewees commented that tourists tended not to know how far from the volcano particular resort areas were, or how far the danger extended. This goes back to the issues around the GEJET: people associated a much wider area with the danger than respondents felt was appropriate.

Some of the respondents were concerned about the Onsen drying up: the Onsen is of major economic value to the tourist industry. There were also other concerns related to economic productivity, particularly around the closure of the echo line (a major highway used by tour buses). As demonstrated by the quantitative data, most people involved in this study had very little knowledge about the volcano. In general, there were many issues raised in the interviews and survey results that could be dealt with via a sustained public engagement programme.

Discussion

The results demonstrate the significance of the warnings in 2015 for businesses in the region, and also include some important reflections on disaster risk reduction in Japan more generally.

Cascading impacts and vulnerability

One implication from this study is that the impacts of hazard events can cascade as much as hazards do – and do so independent of links between hazards. If populations are subject to a series of disasters, even over multi-year timescales, the impacts of those events can be partially cumulative – a problem familiar in the context of small island states, for example (Pelling and Uitto, 2001). Recovery is a complex process even when one event has occurred, but when several occur in succession – such as GEJET, heavy snow and then volcanic activity – the impacts are sustained and complex (Pescaroli and Alexander, 2015). They are also not purely economic – while this study focussed on businesses, it was clear that the psychological impact of the disasters was also significant, not only for the respondents but also for their customers. While much work has been done on disaster recovery, this has tended to focus on the impact of a single disaster rather than the combined impact of several. In the case of Zao, there was only the GEJET "disaster": the Zao crisis only involved a period of raised alert level, and yet it had significant impact on the region according to the interviewees and the respondents. Their comments strongly suggest that GEJET had sufficiently increased their vulnerability to further disasters and even to periods of uncertainty: it had lowered their income whilst also creating expense for some (e.g. the interviewee who was still rebuilding). The warning period then further decreased sales. This underscores the point: impacts from warnings as well as from hazards should be taken into account in policy formation and economic planning.

A further challenge, however, was that the two events (GEJET and the warning period) overlapped in their impacts, because respondents had not entirely recovered from GEJET. They therefore felt that it was challenging to distinguish the impacts completely – the impact of GEJET was effectively prolonged by the warning period. This suggests that there is considerable complexity in forensic examinations of disaster impacts across time periods, perhaps particularly when the scales and nature of the events are very different. This finding is relevant for forensic approaches that seek to understand the impacts of apparently single events.

Governance and perception of forecasting

While government help was appreciated, it was also viewed as too simplistic to help much in practice. Economic aid was clearly valued, but the overwhelming sense from the interviews in particular was that there was not enough help with information, before, during and after the crisis. This was not just information about the state of the volcano, but also with conveying messages

about safety after the end of the crisis period. In part, this may stem from an inability to state that the volcano is safe (since any active volcano is always potentially dangerous – as evidenced by the explosion of Ontake). However, a statement that the increased activity had subsided to background levels might have been useful.

The respondents tended to view short-term forecasting as easier than longer-term, but those who had used government sources of information (rather than media) tended to have a more realistic view of the ease of short-term forecasting. This might be due to differences in the wording of warnings, and in the nature of media reporting versus official documentation. This is interesting because it suggests that the government communication may have been more appropriate, but was not adequately communicated via the media.

Trust

The results also suggest that trust in the various groups was linked to perception of the potential impacts of an eruption, and to forecasting skill. Trust was higher among those who felt that impacts would be significant and forecasting is easy (so likely to be accurate). There were also indications from correlations that trust is partly a feature of personality, with some people who are trusting also tending to be cautious. This is consistent with previous studies (Eiser et al., 2015).

The significance of concern about false alarms in predicting trust was less than the importance of both impacts and forecasting skill, but still important at the 5% level. This is unsurprising in the context of the interview and qualitative survey results, in which a number of respondents expressed concern about rumours and the fact that the volcano did not erupt (Dillon et al., 2011; Eiser et al., 2012). There were also indications that trust has been eroded as a result of the crisis, since respondents were critical of government and particularly media.

All of the issues around trust are symptomatic of the challenges around understanding and communication. This is not purely a matter of public understanding of science, since there is also a need for the authorities and experts to understand the needs that people have, and how their need for information impacts their behaviour. The communication of uncertainty might also have helped significantly in improving understanding of the alert and emphasising that the lack of an eruption was not really a false alarm (Hincks et al., 2014). While the link between ease of forecasting and trust is a bit concerning in this regard (since awareness of how hard forecasting is might lower trust, on first appearance), it is also possible that clearer communication of uncertainty would remove this factor from the model: other work suggests that accuracy of forecast is not the most important factor in trust (Eiser et al., 2015).

Social fabric and the perception of space

Two key areas of perception concern the geographical environment and the human context. The perception of distance around a disaster zone was raised by interviewees both with reference to the Zao crisis and to GEJET. Respondents felt that tourists viewed the entire region as dangerous, and had poor geographical knowledge. They attached a larger area on a map with a name than was appropriate. Furthermore, connectivity with other regions was also a factor: those who had friends in regions that experience volcanic risk (such as Kyushu) tended to adopt the stories that those friends had told them. Similarly, the media acted as a gateway for such stories – in this case, the story of Ontake: they were viewed as spreading “harmful rumours” that likened the Ontake events to those that might happen at Zao. This appeared to also feed off ongoing stigma attached to the region due to the Fukushima-Daiichi crisis – also noted by other authors (Bachev and Ito, 2014).

This lack of geographical awareness led to several reactions. Some hotel owners felt an additional responsibility to their guests as a result of their local knowledge, and emphasised this civic responsibility as a reason for needing better information and some dialogue with authorities. Many were frustrated with the lack of knowledge that long-distance guests had about the region, particularly its distance from Fukushima. However, this is both a problem with geographical knowledge about maps (Haynes et al., 2007b), and also with knowledge about hazards and their spatial scales – something that was also lacking among the respondents themselves as evidenced by the hazard perceptions data. The challenges were also symptomatic more generally of the volume of information available to the public about hazardous events – there are perhaps some similarities here with the "google your symptoms" trend in medicine and its links with health anxiety (White and Horvitz, 2009): there was a feeling that potential customers were being put off because they had access to information that they could not adequately triage. This contrasted with the view that several interviewees recalled prior to the crisis: that they had not realised Zao was a volcano. This is consistent with previous studies (Greene et al., 1981) at active volcanoes: the timescales of volcanic activity tend to be longer than human lifetimes, and memory is lost.

Risk perception

The perception of the likelihoods of hazards was relatively good in relation to scientific assessment (Kuri et al., 2017), although there was a tendency, especially obvious in interviews, that hazards recently experienced in Japan were rated more highly. This is consistent with the availability bias (Tversky and Kahneman, 1973), which is consistently reported in hazards research (Demuth et al., 2016; Huang et al., 2016; Perry and Lindell, 2008).

Respondents in Miyagi viewed the hazards as greater, and also tended to be less concerned about false alarms. This may partially be the result of the local topography: those in Yamagata are protected from the most hazardous flows, but are nevertheless vulnerable. Furthermore, there were differences in how the Prefectures had approached informing the public, particularly in holding seminars, with Miyagi respondents in interviews being rather more aware of information availability in this format than those in Yamagata.

Public engagement

Reducing the vulnerability of populations to disasters includes the inclusion of populations in risk planning (e.g. Gaillard and Mercer (2013)). Participatory techniques, for example, offer a means of combining local and scientific knowledge (e.g. Pelling (2007)). Citizen science is another method that is increasingly being used to involve communities in risk reduction and scientific data-gathering (Crain et al. (2014); see also Irwin (1995)and Haklay (2013) for discussion of the broad context of citizen participation in science). A conclusion of this paper is that the communities around Mount Zao would benefit from greater visibility of not only scientific information about the area, but also some engagement with the processes of decision-making and risk reduction: risk perception and scientific knowledge about the volcano were relatively poor, and there was a great deal of anxiety that the media held most of the power in risk communication, with inadequate engagement from government and experts. The reasons for low risk perception may relate to the lack of prior experience (Huang et al., 2016; Lindell, 2013), or to the experience that this event did not lead to an eruption – since there was no previous event in living memory, we cannot adequately assess this. In such contexts in particular, where there is no experience of hazardous events, it is not enough to employ a top-down, linear model of science communication. Science communication, and risk communication, involves dialogue, and dialogue involves listening (Pidgeon and Fischhoff, 2011).

Conclusions and recommendations

This study suggests the need for a sustained public engagement campaign in the Zao area – and potentially around other active but not erupting volcanoes in Japan. Such a campaign would be most effective if it included dialogue with the public rather than top-down education, and if it included a range of institutions, including government, the JMA and university groups. It would also benefit from being coordinated across the different prefectures, so that information is consistent. Furthermore, the alert level system and decision-making procedures should be clear to the public: many studies have shown that transparency is important in this regard. It is also important that the needs that people have are taken into consideration, to avoid the blanket imposition of policies that only benefit a fraction of the population.

The paper also shows the impact of non-eruptions on populations around volcanoes. The most famous example of this is the 1976 phreatic activity at La Soufrière de Guadeloupe (Hincks et al., 2014; Tazieff, 1977). However, in the case of Zao, the activity was much less visible but still presented an increase in the risk of eruption. In this case, a number of actions were suggested by the respondents that might help in such cases – such as information about the end of a crisis as well as its beginning. The conjunction of the crisis with the recovery period after GEJET was also significant for many respondents, demonstrating that the impacts of consecutive crises can cascade to increase vulnerability, and this needs to be considered in planning.

Finally, the case study also demonstrates something of the complex synergies between people and their environments. The people who live on Mount Zao are dependent on it being a volcano (for the Onsen, the farmlands, the aesthetic appeal), and yet are also vulnerable to its behaviour as a volcano. This vulnerability is enhanced or mitigated by the behaviour of those in positions of power – including both scientists and government actors – and reveals the non-linearity of volcanic risk and its management: only when the needs of populations are discussed alongside the potential volcanic activity can progress be made.

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